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STUDY OF NSI AND RELATED CABLE PERFORMANCE DURING TESTS PERFORMED IN THE NASA HOT GAS FACILITY

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FOREWORD

This report documents the tests performed on various cable configurations to evaluate the Nozzle Severance, Insulated (NSI) and other cables inside the Space Shuttle Solid Rocket Booster (SRB) aft skirts. The work was performed under Contract NAS8-32982, "Solid Rocket Booster Thermal Protection System Material Development." The NASA Contracting Officer's Representative for this work is Mr. Bill Baker, EP44.

INTRODUCTION

Some seven different configurations of the NSI and other cables were tested in the NASA-MSFC Hot Gas Facility (HGF). The tests were conducted to study what happens to the cables when they are exposed to hot flow as was the case in the first two Shuttle flights, the STS-1 and STS-2. The thermal curtain around the aft skirt aft ring and the nozzle compliance ring failed during reentry on both these flights allowing the flow to get to the inboard equipment and cables. Protection of these components is vital for various functions especially to attain proper nozzle separation. There was a nozzle separation failure on the right-hand SRB on STS-2. The tests in the HGF demonstrated the severity of the aerodynamic forces combined with aero heating environment on the test cables and helped, in general, to evaluate the cable wrap materials and cable mounting hardware and technique. "Blastape II" made by Johns-Manville is utilized to protect the NSI cables. The tape is made of asbestos, Inconel wire and a special flameproof compound. The "Blastape II" cable wrap which is adequate for thermal protection of the cables must be properly clamped at its ends. The nylon clamps (or ties) used to secure cables to metal components inside the skirt could not withstand the heating. K5NA closeout material used on the outboard surface of the aft skirt when troweled over the cables performed excellently in protecting the cables and mounting hardware. Also a thick layer of "Insta-Foam" over the cables was sufficient to protect the cables.

TECHNICAL DISCUSSION

The cable test models were built on test panels and all, except one, were mounted in Test Position 1 of the Hot Gas Facility test section where the clean body heating rate is the lowest attainable. A typical cable loop model is shown in Fig. 1. It consists of a length of flight cable with a clear plastic sheathing which is layed on a length of cable wrap material called "Blastape II." This tape is simply folded over the cable along its length and this arrangement is mounted on a base plate by means of hose clamps as shown in Fig. 1. The model was subjected to 60 seconds of cold flow during which no damage to the cable or its wrap was apparent. It was then subjected to 6.03 seconds of hot flow which failed the insulating Blastape and exposed the cable as shown in Fig. 2.

Figure 3 shows a short length of flight cable and connector, both wrapped with Blastape. The tape is wrapped spirally around the connector first and then on to the cable with at least a 50% overlap of the tape material. The connector is mounted in the base plate and the other end of the cable is fastened to a small vertical bracket. This model was also exposed to 60 seconds of cold flow and then 6.04 seconds of hot flow. It is theorized that the top end of the cable broke loose first allowing the cable to flap in the flow and thus causing the entire wrapped material to be lost at once (See Fig. 4). Another model of the same configuration was made up with the end of the cable fastened more rigidly as shown in Fig. 5. The results, however, were similar as shown in the post-test picture of Fig. 6.

To simulate yet another area of the NSI cables in the aft skirt, a model shown in Fig. 7 was made up. It consisted of two 1/8-in. diameter flight type cables spaced 1/2-in. apart and clamped between steel blocks at a representative distance apart on a flat aluminum panel partially protected with cork. After 26 seconds of test, when the run had to be terminated due to aluminum temperature directly under the cables having reached 400 F, all cork was lost (probably due to faulty bond). The cables looked good but were sagging a little as seen in Fig. 8. This test was repeated and results were the same as far as cables were concerned (see Figs. 9 and 10). Yet another repeat run was made with the exception that the aluminum backface temperature was allowed to rise above 400 F in order to obtain a longer test duration. The result of this test which lasted 50.3 seconds is depicted in the photograph of Fig. 11 where one portion of cable was lost and another was loosened.

Figure 12 is also a cable model similar to the one shown in Fig. 9. Here the cables are wrapped individually with "Blastape II" and fastened with nylon ties that are bonded with EA 934 to small steel plates bolted to the aluminum base. A post-test picture of this model is shown in Fig. 13. The two cables shown here were recovered later after the test. The clamps could not be found and are believed to have disintegrated due to the heat early in the test which was run a full 60 seconds (maximum run time in HGF). In order to find a solution to the problem of proper cable mounting technique, the model of cables with Blastape and nylon ties was taken and a ramp of K5NA closeout material was built up over the cables as shown in Fig. 14. This model was run for 60 seconds also and virtually no damage, aside from the normal char formation, was indicated.

Figure 15 is a photograph taken from inside the aft skirt of A-11 showing a cable routed in a U-shape over the aft skirt aft-ring. This cable configuration is the subject of the next test model shown in Fig. 16. The cable as seen is wrapped with "Blastape II" and routed on the test panel in the manner shown in Fig. 15. It is fastened with nylon ties threaded through nylon bases bonded to the test panel with EA 934. The cork on the downstream half of the panel is to protect the aluminum base plate in the higher heating rate region in the HGF. The cable was lost during the test again because the nylon ties could not withstand the heating. These ties, broken in pieces, are shown in Fig. 17 with the relatively undamaged cable recovered after the test.

Aft skirt rerouting cables are depicted in the photograph of the inboard surface of A-12 in Fig. 18. This type configuration of cables including the mounting ties and typical spacing between ties was simulated with a cable model built on a flat test panel. Post-test photographs of the model shows that the cable came loose completely from its clamps, a problem encountered in earlier tests (see Fig. 19).

An alternate cable wrap material known as "3M Heat Barrier Tape SJ8000X" was tested. The 3M tape is a very pliable, easy-to-wrap tape as opposed to the thick and hard to spiral wrap "Blastape II." The 3M tape had been tested earlier during the strut cable wrap materials evaluation test program and had failed; so it was believed that two layers of the 3M tape and one additional layer of aluminum foil tape (Specification No. STW4-2543), both spiral wrapped with at least 50% overlap to render a total of 6 layers over the cable, would be adequate. This cable wrap was tested under identical conditions as were the other materials during the strut cable evaluation test program. The test model shown in Fig. 20 was mounted in Position 4 of the HGF test section. The temperature of the surface of the cable reached 300 F in 12 seconds and the test cable was destroyed (see Fig. 21) before the run was terminated at 14.8 seconds.

The cable test model of Fig. 14 had two thermocouples on the back side of the panel and under the K5NA ramp. These thermocouples recorded maximum temperatures of only 142 F since they were located directly under the hump of the K5NA material. The temperature of the bond line between the K5NA and the aluminum panel would be higher at the start of the ramp. It was necessary to know the maximum bond line temperature attained during the 60-second test to aid in establishing the upper temperature limit for the bond between K5NA and the aluminum. Additional thermocouples were installed for this purpose on the previously tested panel of Fig. 14. The panel was rerun for about 28 seconds only, since the bare aluminum in front of the panel reached 480 F and the run had to be cut. The thermocouples under the panel where the ramp started read 350 F at the end of the run and post-test inspection of the panel showed no signs of debonding between the K5NA and the aluminum base plate.

Figure 22 shows a ramp of "Instafoam" made up in a 3 in. deep steel pan that is 28 in. long and 22 in. wide. The pan carries assorted cables at its bottom, with a thermocouple attached to each one, buried in the foam. The pan was mounted in Position 1 of the HGF test section where the average heating rate on the ramp is estimated to be 11 Btu/ft^2-sec. Fig. 23 shows the condition of "Instafoam" after 77 seconds of hot flow over it. The thermocouples did not respond since they were buried deep in the foam.

OBSERVATIONS

The qualitative observations that can be made from the cables tests are:

- The "Blastape II" is a good cable wrap material but when wrapped on the cables or connectors needs to be clamped securely so that it cannot slide off the cable.
- The nylon cable ties used to clamp the cables are not suitable when they are exposed to the hot flow.
- Bare cables should not be exposed to hot aerodynamic flow, for they will surely fail.
- Cables and their fastening devices when protected with K5NA closeout materials will not fail and the K5NA will not debond from its applied surface when the surface gets to at least as high as 35C F, perhaps higher.
- The 3M Heat Barrier Tape, though easy to wrap cables with, is not as good as the "Blastape II" for thermally protecting the cables.
- Cables when buried under 3 in. of "Instafoam" would survive the heating predicted for thermal curtain failure, though it is not known how well it would take the aerodynamic and aero-shear forces.

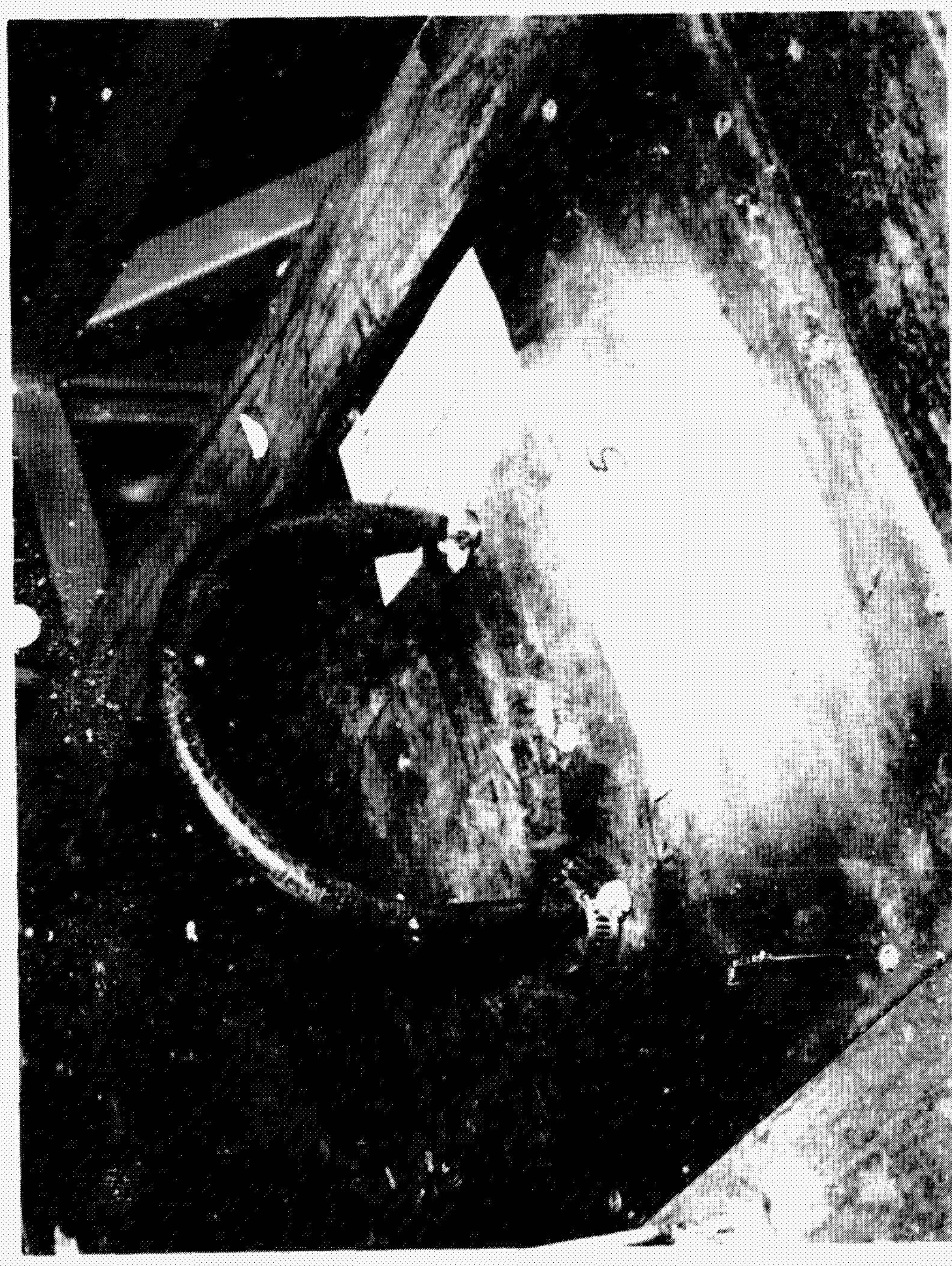

Fig. 1 - Cable Loop Model Showing the Looped Cable Wrapped with Blastape II Mounted on HGF Test Panel

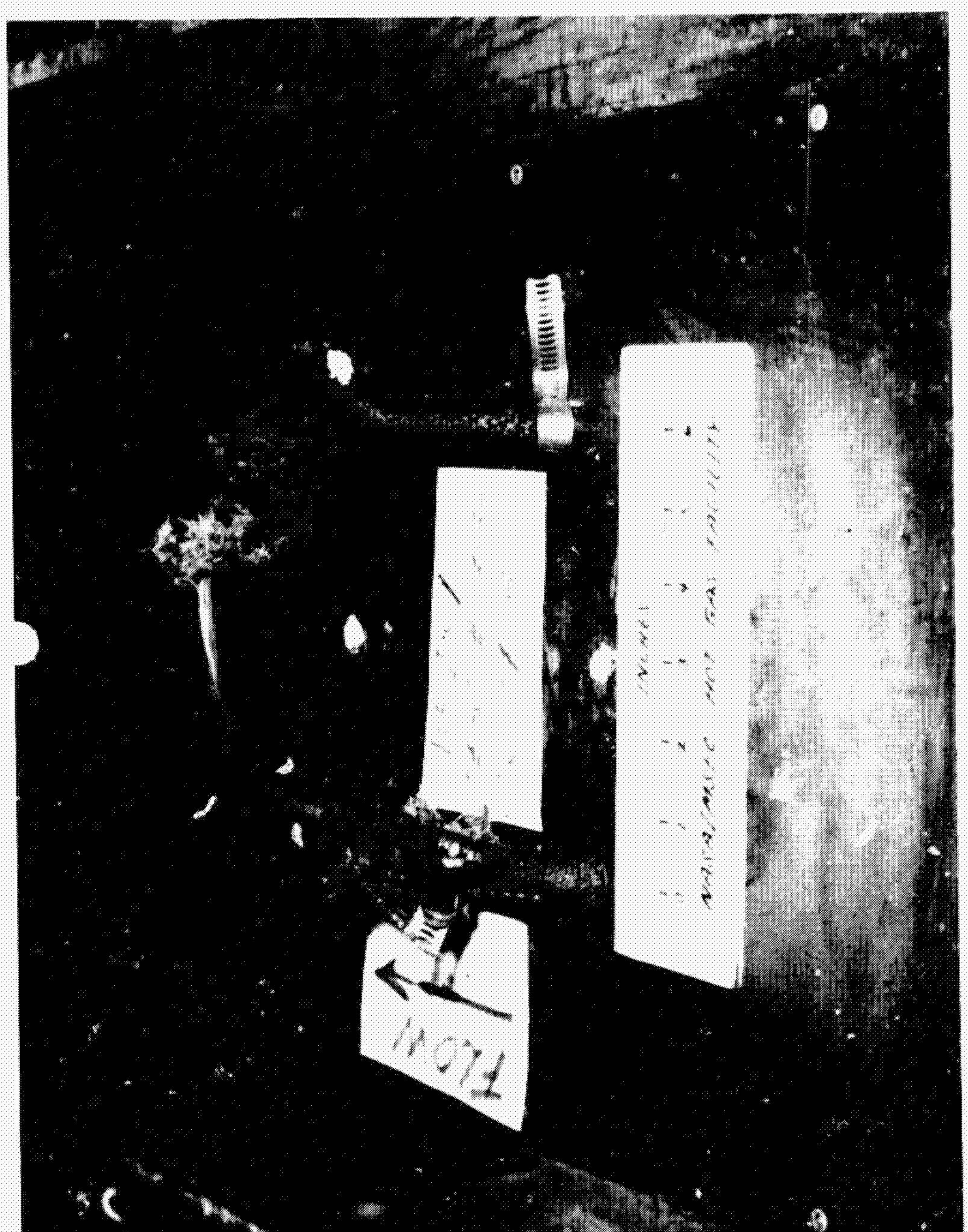

Fig. 2 - Post-Test Photograph of Cable Loop Model

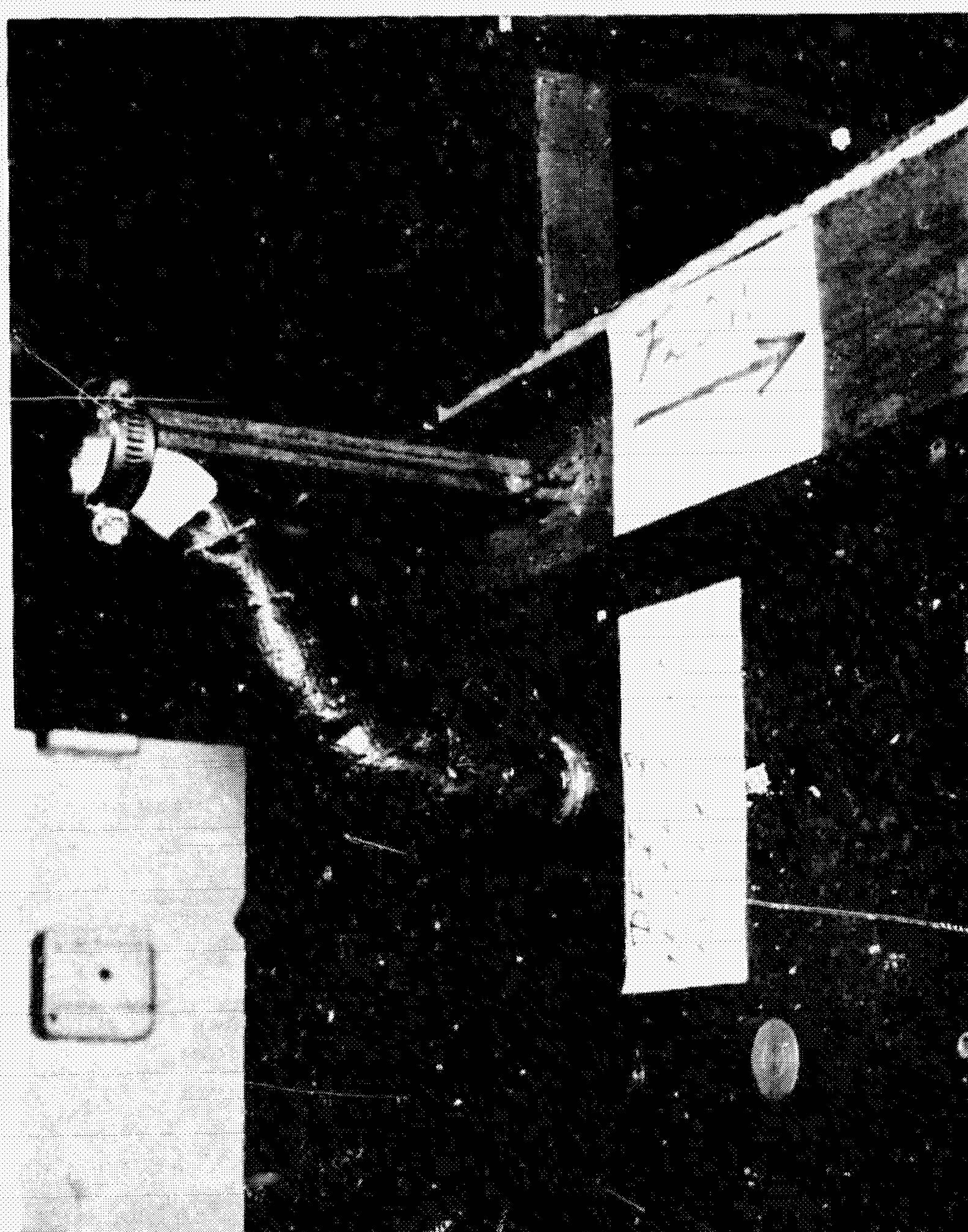

Fig. 3 - Short Length of Cable and Connector
Wrapped with Blastape II

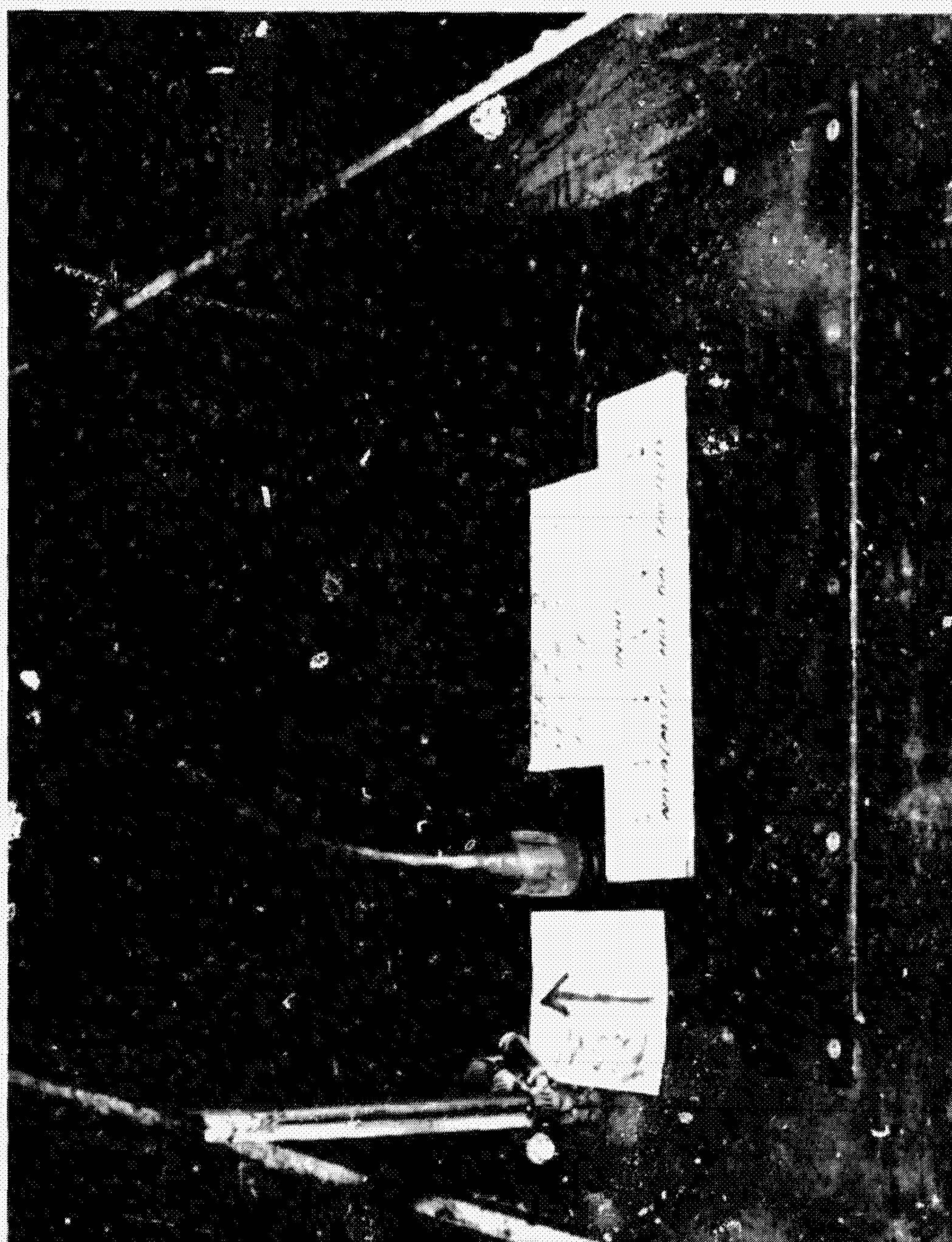

Fig. 4 - Post-Test Condition of Model (Fig. 3) Indicating Loss of Grip on Top End of Cable and thus Loss of Wrap Material

Fig. 5 – Test Model of Cable and Connector Wrapped with Blastape II with a Different, Firmer Fastening Method for Cable at Top End

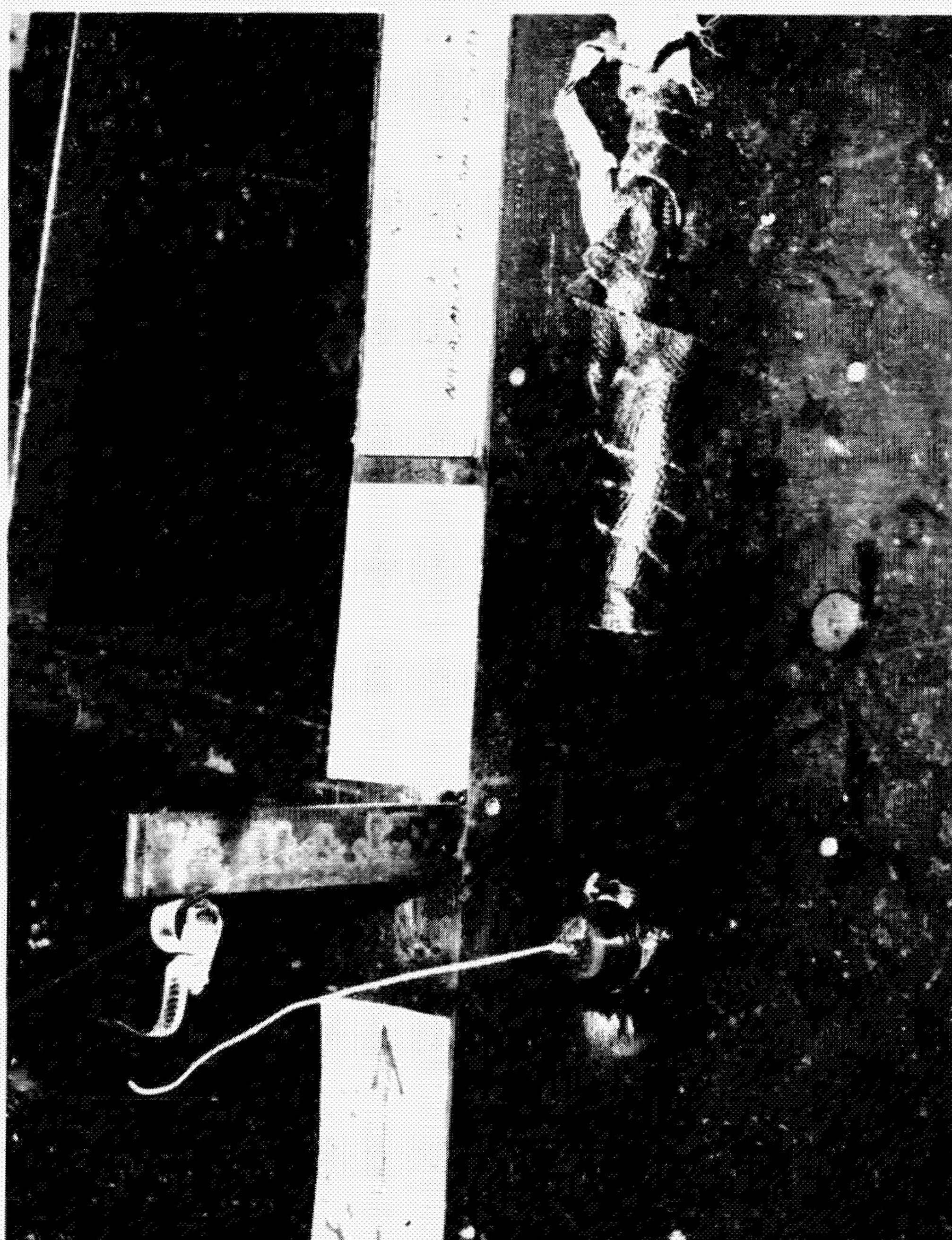

Fig. 6 - Post-Test Condition of Cable with Results Similar to Specimen Shown in Fig. 4

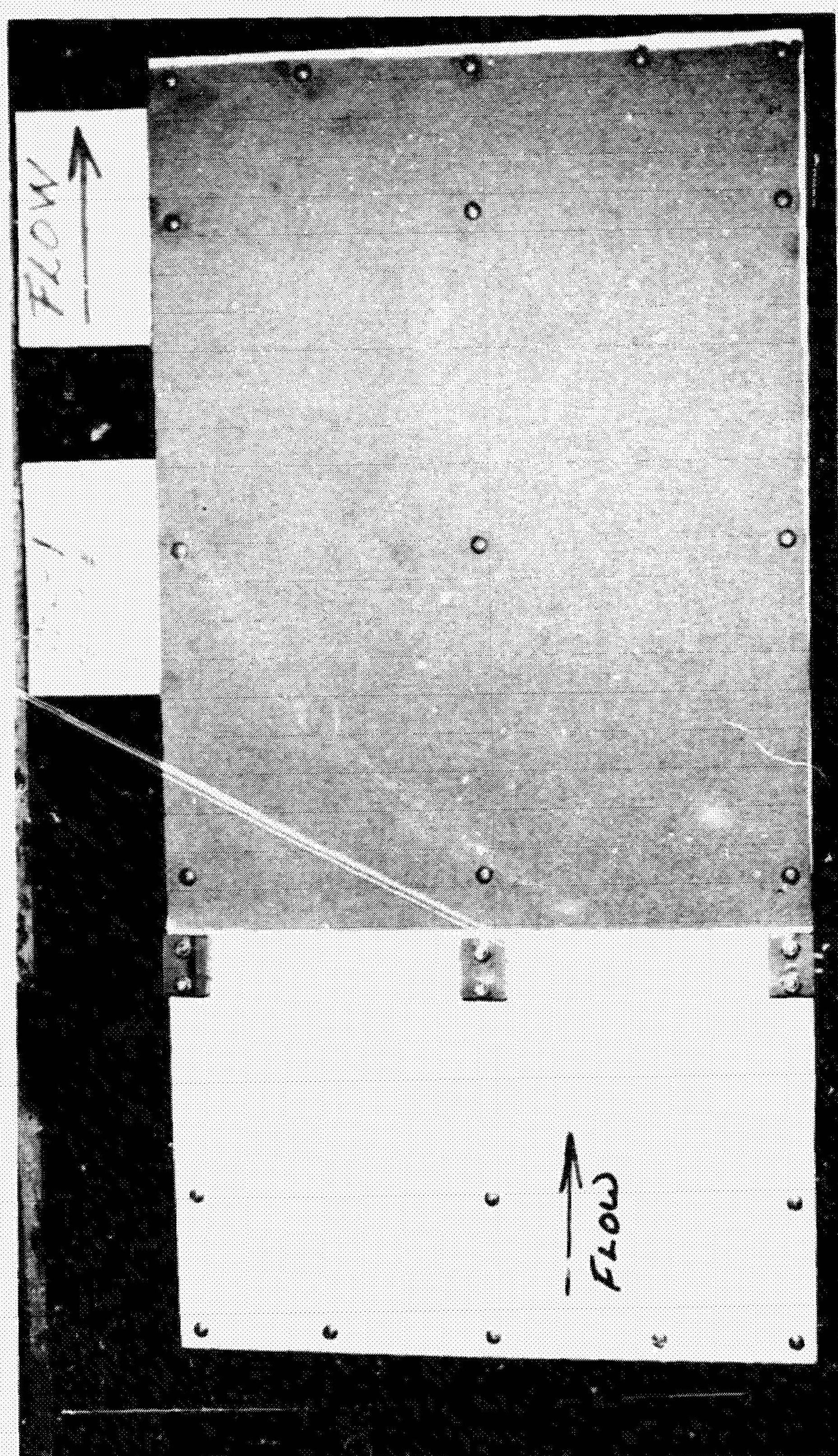

Fig. 7 - Typical Aft Skirt Internal Cable Configuration Model (The Cork Downstream of the Cables is for Aluminum Panel Protection in the Higher Heating Rate Zone of Test Position 1 in HGF)

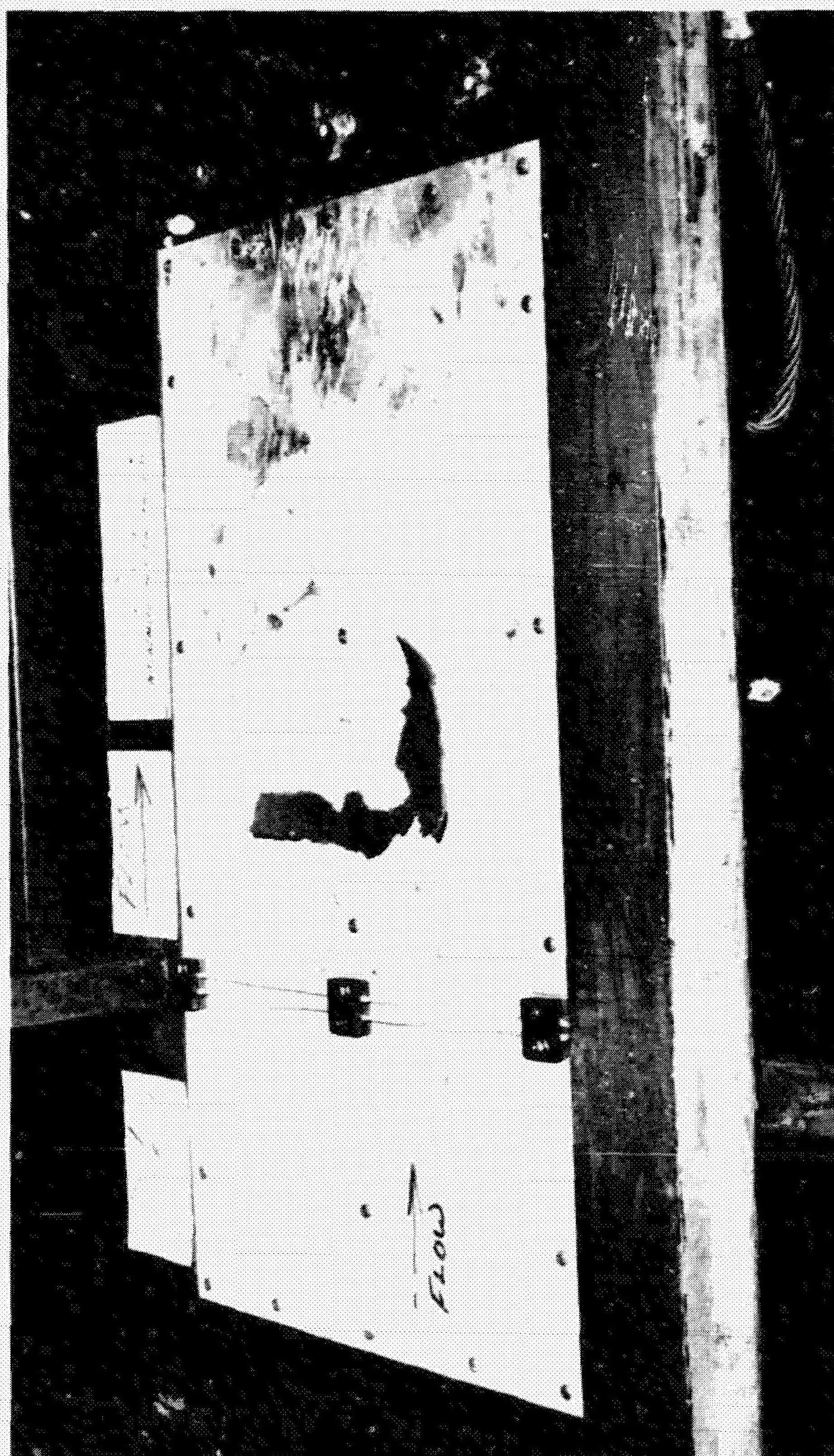

Fig. 8 - Loss of Cork Indicated Due to Improper Bonding
(Note Sagging Cables)

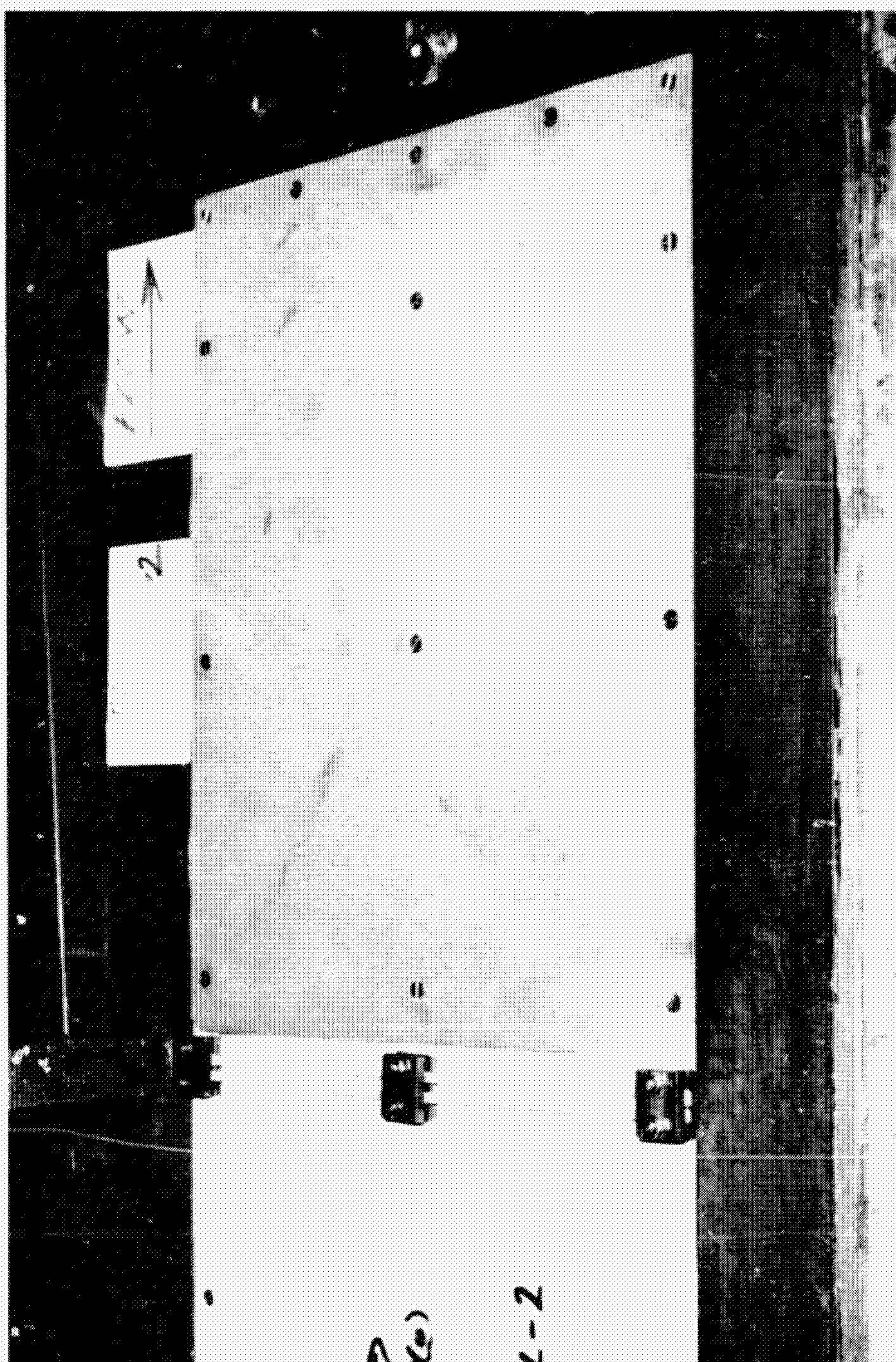

Fig. 9 - Repeat Test Model of Specimen Shown in Fig. 7

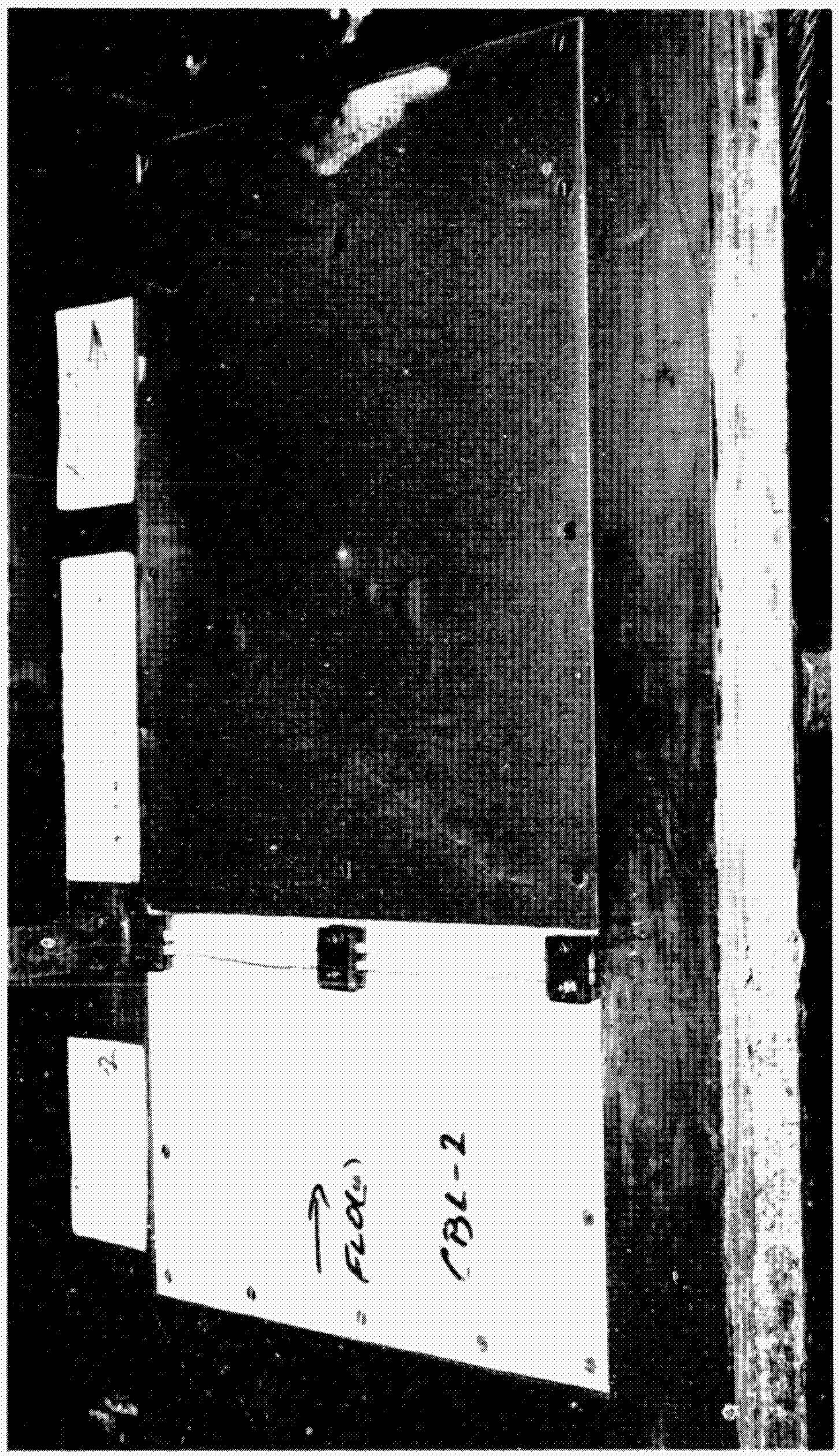

Fig. 10 - Results of Test on the Cables Mounted on Panel are Similar to Those on an Identical Test Setup of Fig. 8

Fig. 11 - Test Duration on This Cable Test Model was Longer Than on Previous Two Models of Figs. 8 and 10 Causing Cable to Break

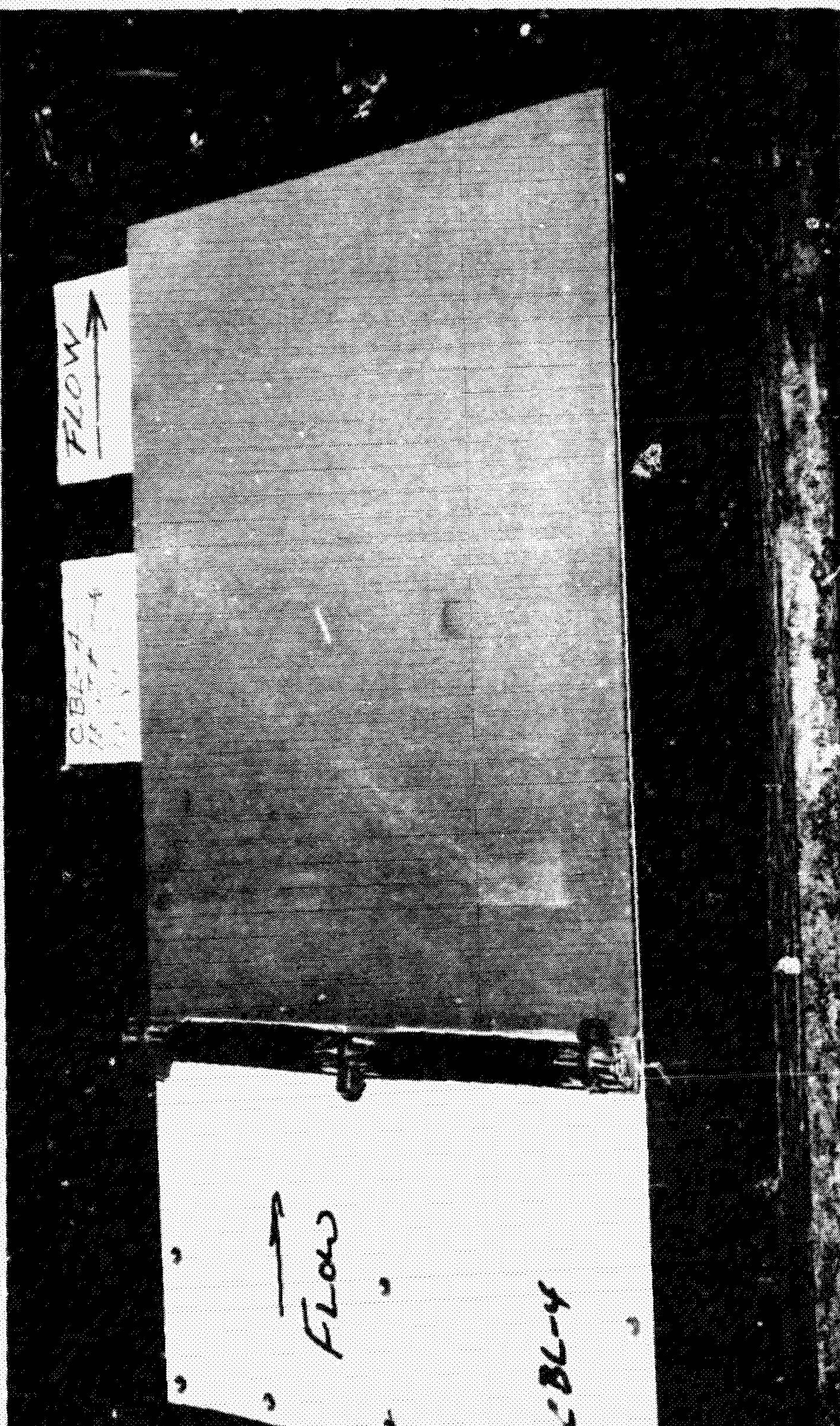

Fig. 12 - Cables on Test Panel Protected by Blastape and Fastened with Nylon Ties Threaded Through Nylon Bases Epoxied to Small Steel Standoffs Bolted to Aluminum Panel

Fig. 13 - Nylon Ties Seen in Fig. 12 Failed Losing Hold on Cables Which Were Later Retrieved

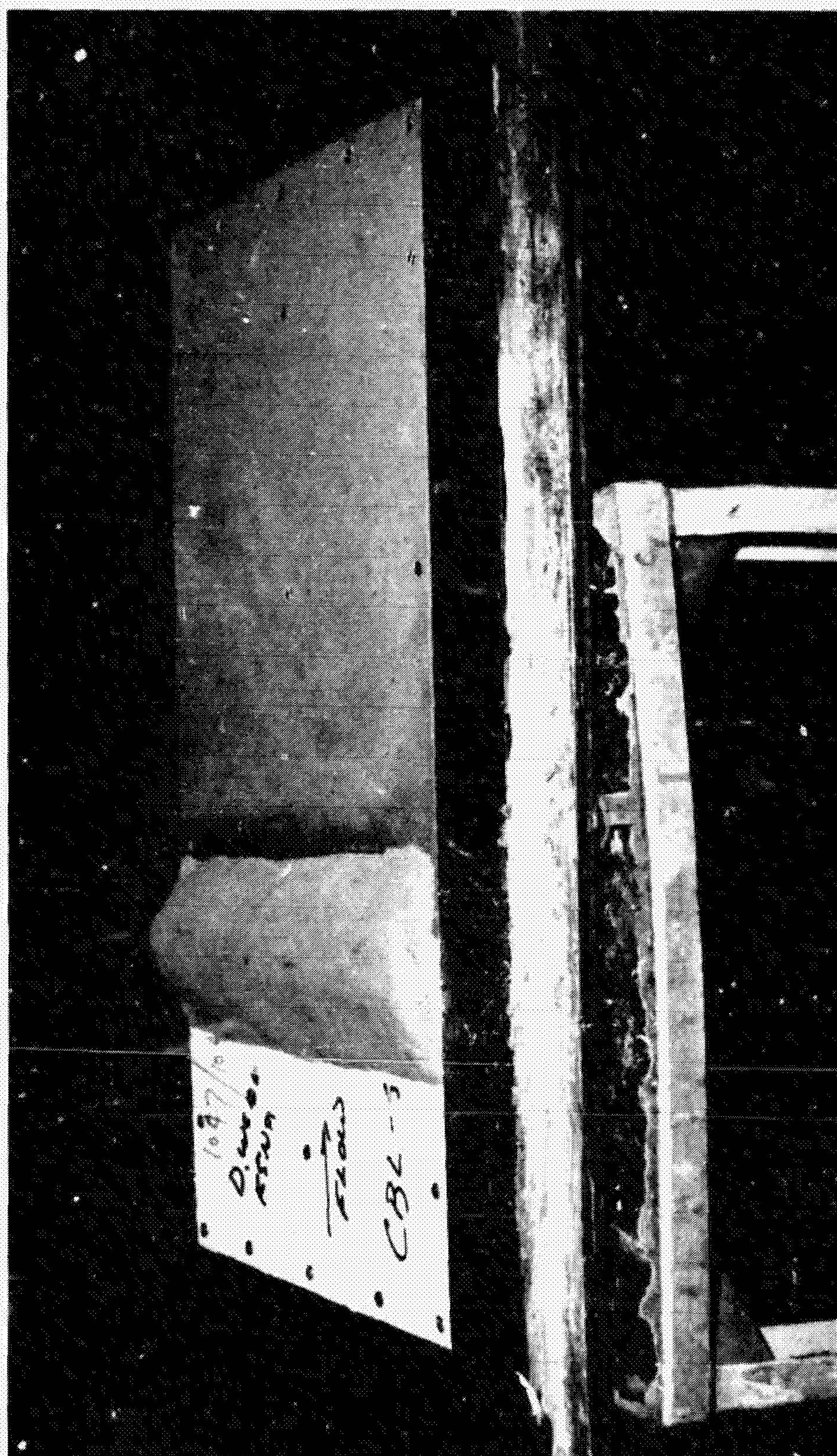

Fig. 14 - Cables and Ties Shown Covered with K5NA Closeout Material
(To Ensure Against Cable Loss)

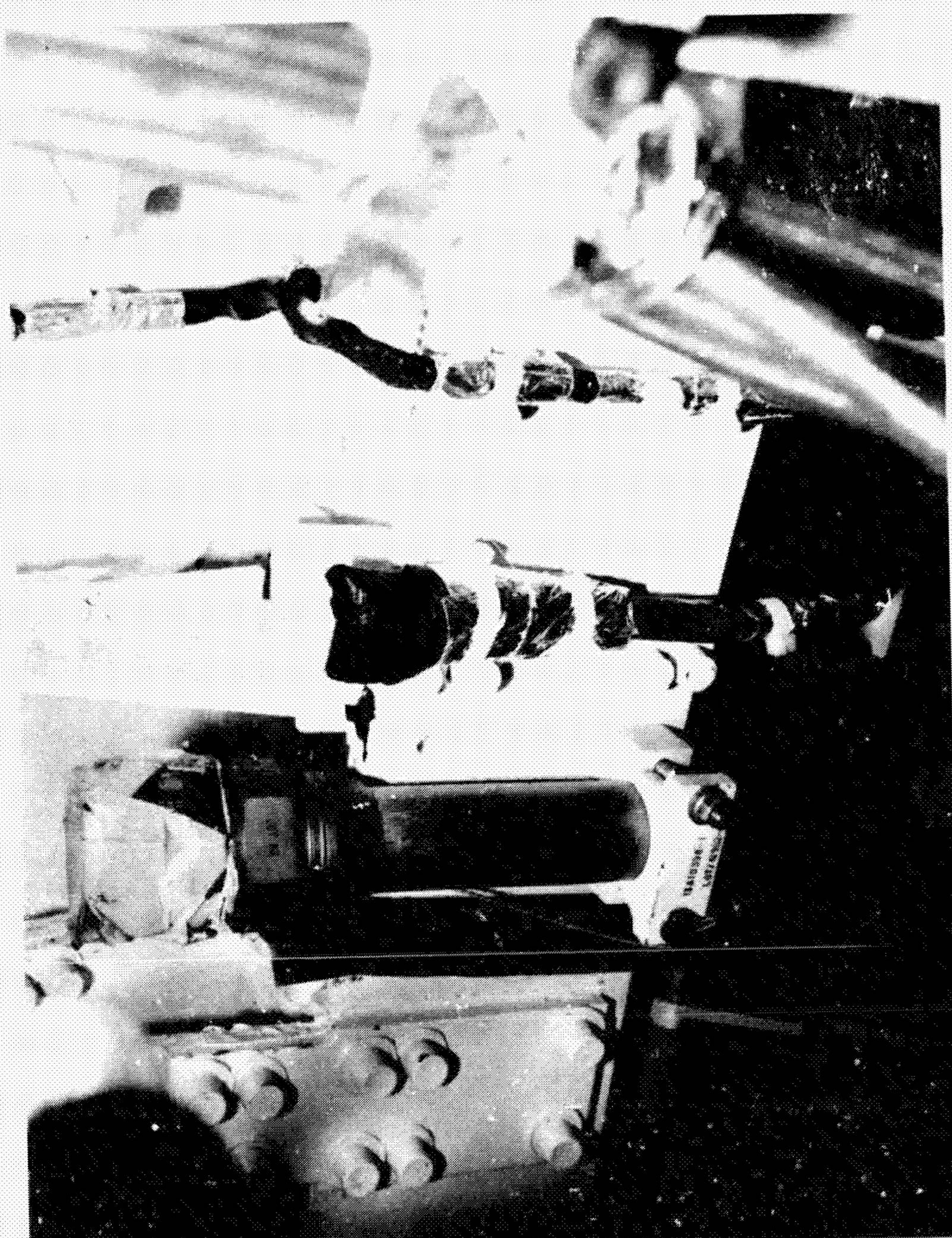

Fig. 15 - View from Inside of A-11 Aft Skirt Showing How One Cable is Looped over the Aft-Ring Flange

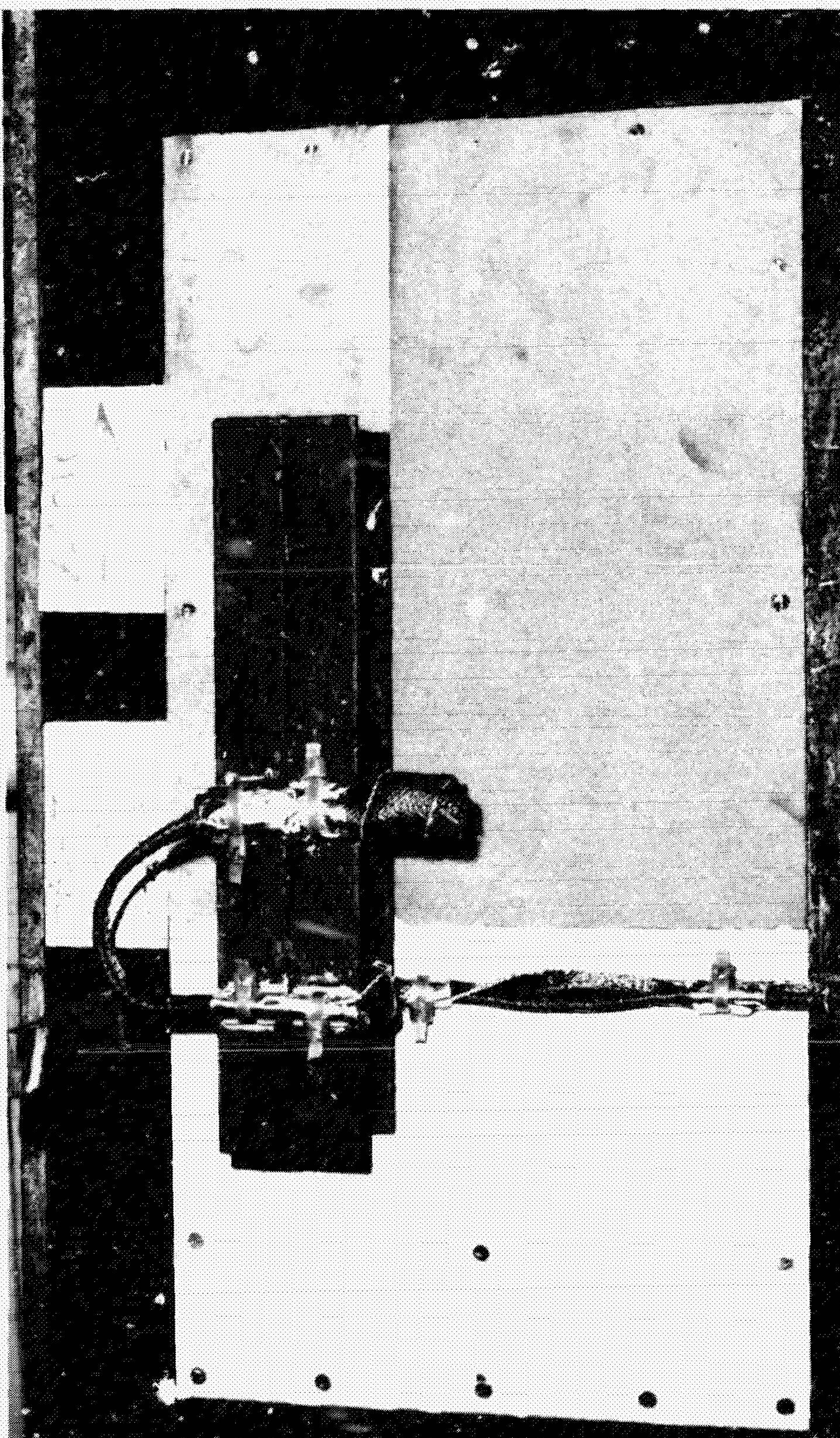

Fig. 16 - Model Prepared to Simulate the Cable Configuration of Fig. 15

Fig. 17 - Loss of Cable is Indicated Due to Failure of Nylon Ties
Used for Fastening Cable

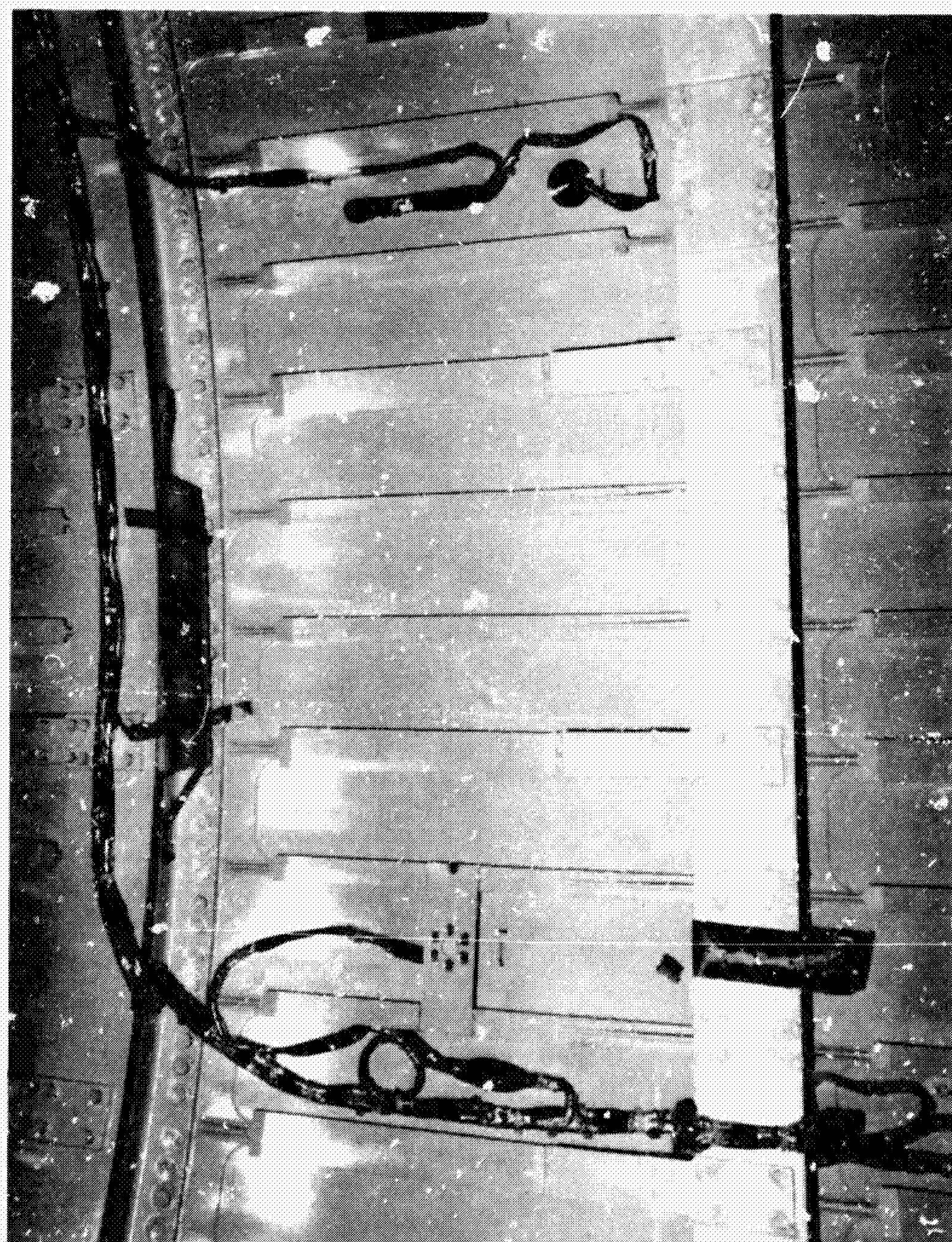

Fig. 18 - Typical Routing of Cables Inside A-12 Aft Skirt

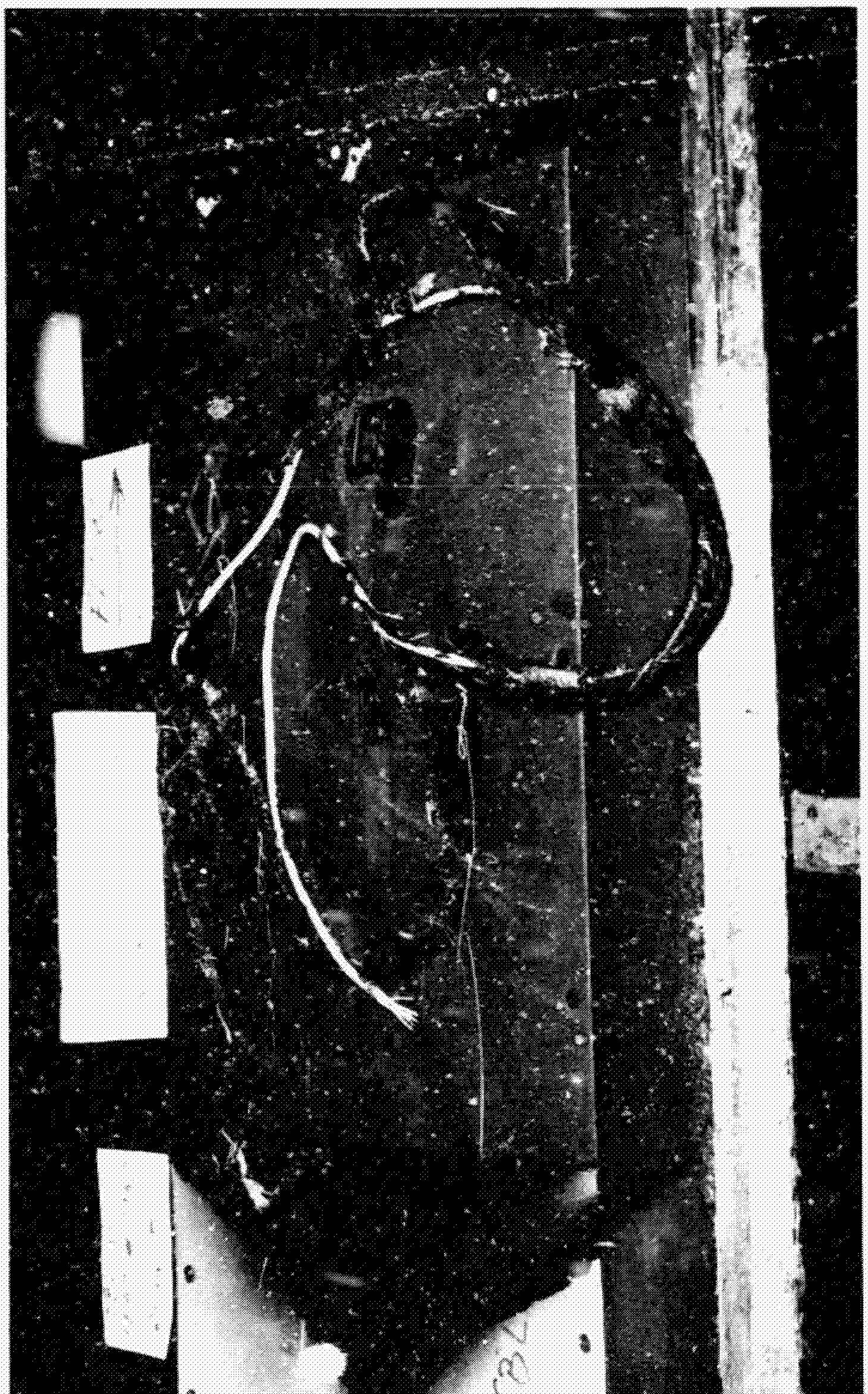

Fig. 19 - Post-Test Condition of Test Panel Prepared to Simulate Typical Cable Routing Shown in Fig. 18

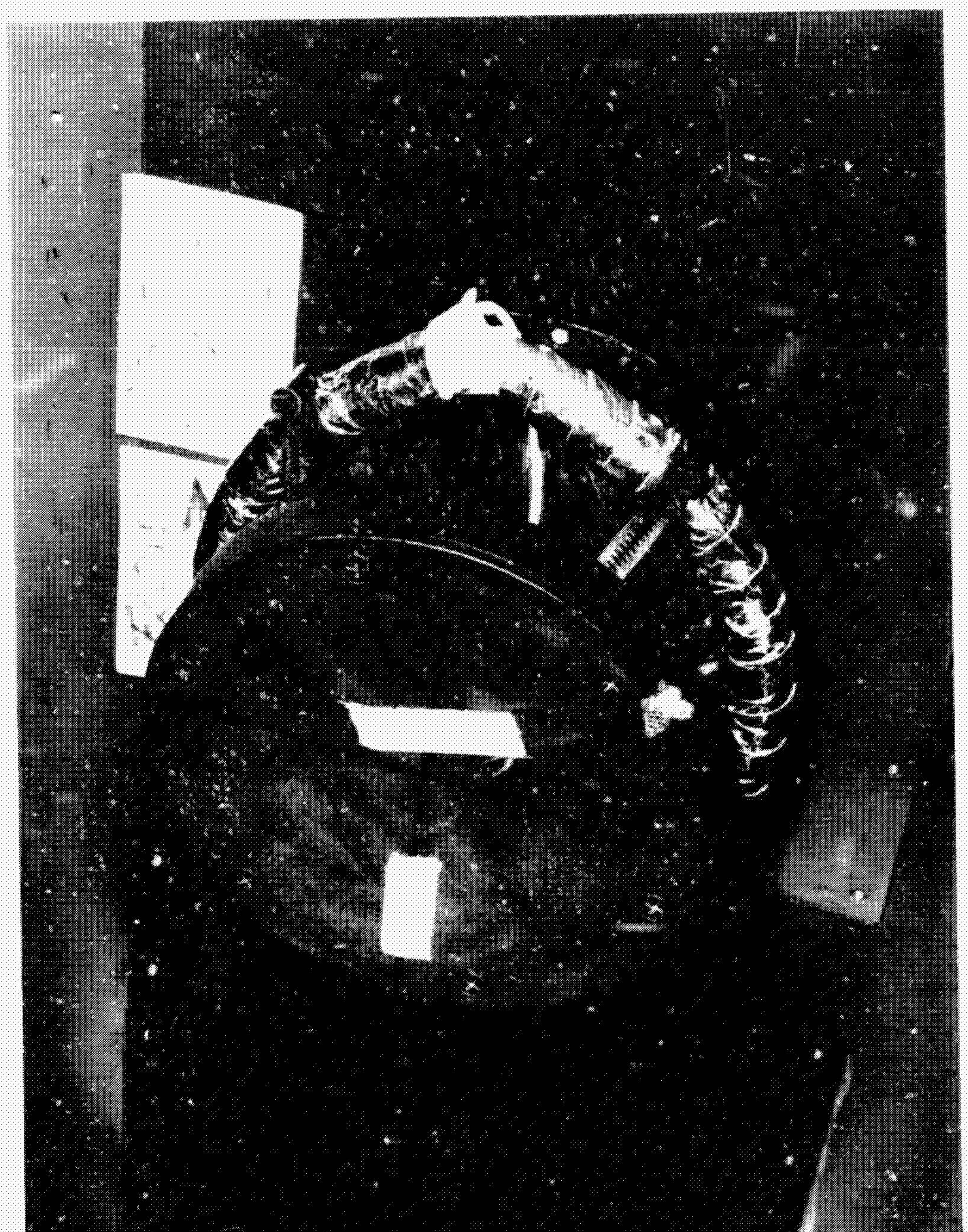

Fig. 20 - Rear View of Strut Cable Test Cylinder Model Showing Cable Wrapped with 3M and Aluminum Foil Tape and Strapped Around Cylinder

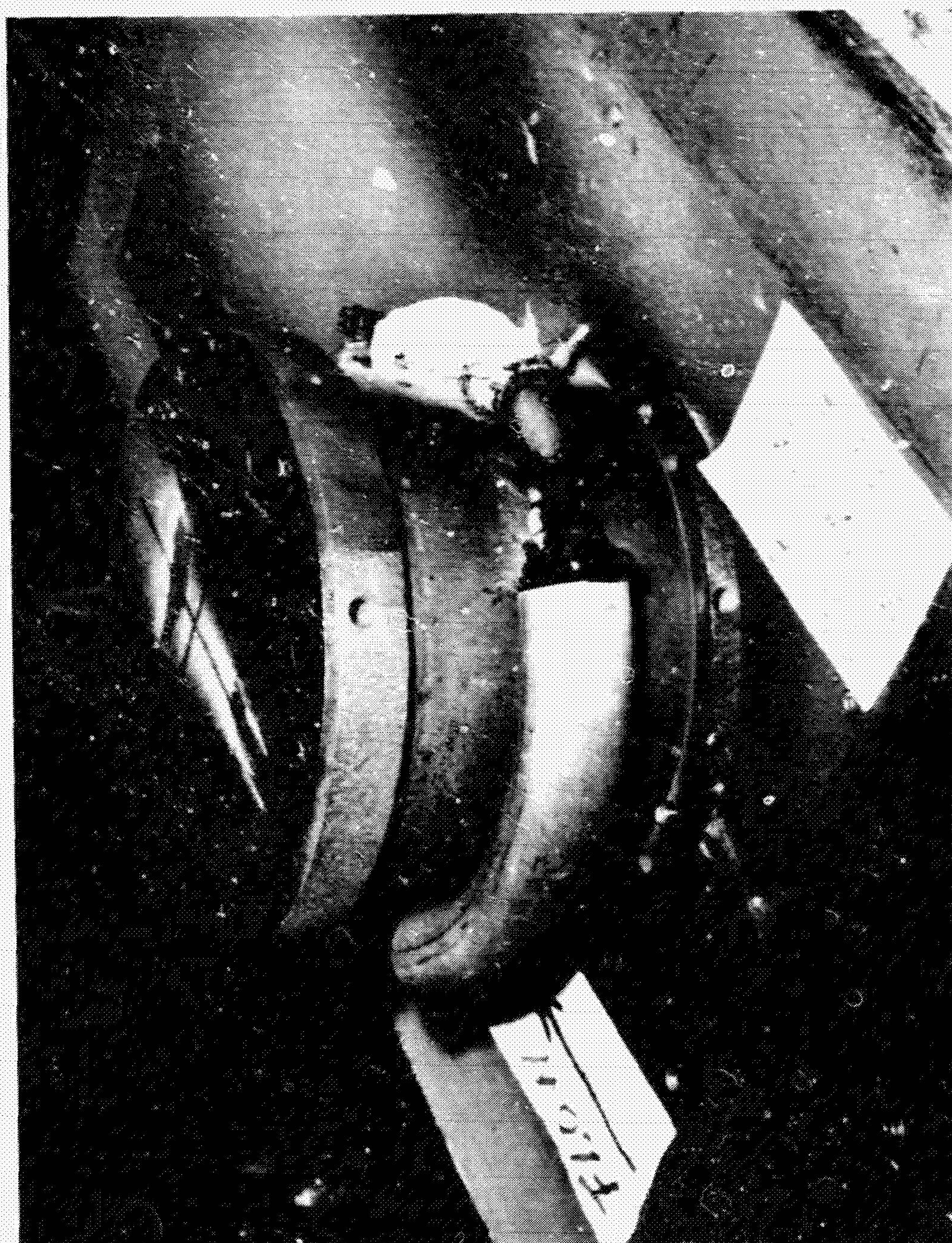

Fig. 21 - Front/Side View of Model After Test Showing the Exposed Cable Which was Wrapped with 3M Heat Barrier Tape

Fig. 22 - Insta-Foam over Cables Model

Fig. 23 - Condition of Insta-Foam Material After Test Lasting 77 s : in Position 1 of Hot Gas Test Facility